Natural Egyptian Sponge Loofah Fiber Effects on Properties of the Egyptian (EAGLE) Unsaturated Polyester

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***Abstract*—Using Egyptian (EAGLE) unsaturated polyester resin and methyl ethyl ketone peroxide catalyst, natural Egyptian sponge loofah (NELS) fibers were created as composite materials for this investigation. Handmade moulds were created for research trials. Separate additions of the fillers were made in various ratios (5, 10, 20, 30, 40, and 50% vol.). The results indicate that adding (NESL) fiber increases the material's hardness and compressive strength. At 50% vol. and 40% vol. (NESL) fiber, (71.84 Hv, 62.60 MPa) respectively, the maximum hardness and compressive strength were reached. Furthermore, it was discovered that increasing the amount of (NESL) fiber from 5% vol. to 50% vol. resulted in a very slight drop in density for the final (NESL) composite under investigation. The present study highlights the feasibility of using Natural Egyptian Sponge Loofah fiber composites as a reinforcing agent in Egyptian unsaturated (EAGLE) polyester. This approach provides a balance between increased mechanical strength and improved mechanical stability, hence expanding the applicability of these composites in engineering domains.**

***Key Words*—Composite Materials, Polyester, Natural Loofah, Density, Mechanical Properties.**

I. INTRODUCTION

COMPOSITE materials can be created artificially or organically. Thet consist of two or more constituent elements, each with unique physical or chemical properties, that stay apart and distinct within the final structure. The majority of composite material consists of a weaker, less rigid matrix with strong, stiff fibers inside [1].

Fiber-reinforced plastic, also known as fiber-reinforced polymer, is a composite material consisting of a fiber-reinforced polymer matrix. While other fibers like paper, wood, or asbestos have occasionally been used, the most common types of fibers are glass, carbon, or aramid. The polymer is typically a thermosetting polyester, vinyl-ester, or epoxy plastic; formaldehyde resins containing phenol are still in use. Fiber-reinforced polymers are widely utilized in the construction, automotive, aerospace, and marine sectors [1]. As fiber-reinforced polymer composites are used more in their current markets and gain traction in relatively new markets like biomedical devices and civil structures, their use is growing at an impressive rate [1].

In matrices made of thermoset polymers, e.g. epoxy or polyester resins, commercial materials generally contain glass and carbon fibers. Thermoplastic polymers may be preferred in some circumstances, since they are malleable after the first production [2]. Additionally, the motivations behind the addition of the fibers (or, in certain situations, particles) to these composites are frequently rather complicated; for instance, improvements in creep, wear, fracture toughness, thermal stability, etc., may be sought [3].

In recent times, there has been a renewed focus on polymer-natural fiber composites due to the need to produce products that lessen environmental pollution worldwide [4].

Unsaturated polyester is a matrix resin that is frequently used to create thermosets, particularly when glass fiber is involved. To create composites, natural fibers such as jute, coir, sisal fiber, straw, rice, husk, and pineapple leaf are mixed with thermosets, natural rubber, and thermoplastic matrix [5-8].

A long history of using natural fibers for engineering can be seen in the use of cotton fibers for insulation foam and wood fiber reinforced phenolic composites for clutch disks [9, 10]. Natural fiber reinforcement in polymers improved the materials' acoustic behavior and thermal insulation while lowering energy production, renewability, biodegradability, and weight reduction. Natural fibers showed comparative similarities to synthetic fibers in a number of specific properties. Natural fiber reinforced composites were used for door panels by a number of businesses, including Mercedes Benz [11, 14].

In the development of polyester/eggshell particulate composites, the density and hardness values of the polyester/eggshell particulate composites increased steadily with the increasing eggshell addition, compressive strength, flexural strength and impact energy increased [15]. Unfortunately, because the primary practical application for Natural Egyptian loofah sponge material has been as a body scrub in bathrooms, there is a dearth of scientific data regarding its mechanical qualities.

The natural cylindrical loofah, sometimes referred to as a vegetable sponge or sponge gourd, is a unique vegetable that also shares a family with cucumbers and marrow [16]. Loofah fiber is made up of lightweight natural fibers that can be used to reinforce lightweight composites because of their abundance, low cost, polyporous structure, and surface morphology, which can promote good adhesion with the

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matrix [17]. Loofah fibers exhibit notable stiffness, strength, and toughness, which are comparable to those found in different metals with comparable densities [18]. Apart from being a vegetable that can be eaten, loofah is widely used as packing material, shoe mats, soundproof linings, bath sponges, utensil cleaning sponges, adsorbent for heavy metal removal from waste water (like nickel, lead, chromium, copper, etc.), and immobilization matrix for bacteria, yeast, plants, and algae [19]. Loofah fibers exhibit notable strength and stiffness, akin to various metals of similar density ranges [20]. Although the loofah species is indigenous to tropical Asia and Africa, Egyptians have been growing it since the late Middle Ages [21].

The majority of studies conducted in the field of natural fiber composites have only looked at the materials' tensile and flexural strengths. The analysis of compressive and hardness properties has been the subject of relatively few works. Investing the natural Egyptian loofah sponge (cucumber fiber) in reinforcement polymeric material (unsaturated polyester resin) is the primary goal of this research. The study also intends to investigate a thermoplastic polymeric compound made of unsaturated polyester as the base material. It also intends to investigate the impact of varying the volumetric fracture of these fibers on the hardness and compressive strength of the prepared polymeric composite material.

David Candra Birawidha, et. al., (2021). Basalt powder has been used as a reinforcing filler in an experimental investigation on the production of polyester resin matrix composites. East Lampung is home to a lot of basalt, an igneous volcanic rock that is not used. Variations in the basalt powder's size, the polyester resin matrix's composition relative to the powder, and the catalyst percentage were the research parameters that were employed. 20 kN of pressure was used to form each sample. When comparing the different parameters of 270 mesh-20% polyester-1/20 and 270 mesh-25% polyester-1/30 catalyst, the highest compressive strength value of 28.331 kgf/mm² was found. Therefore, it is important to pay attention to the proper grain size when using basalt rock powder as a filler in order to obtain the desired mechanical properties [22].

Hashim S. M. and Salih W. B., (2020). This study produced a polymeric composite at room temperature using volumetric fractions percentages (0%, 0.5%, 1%, 1.5%, 2%, 2.5%, and 3% of coconut fiber) and unsaturated polyester resin as the base material. Research was done on the composite material's hardness and compressive strength. The mechanical qualities, such as compressive strength and hardness, improved, according to the data [23].

Suad H. Aleabi, et. al., (2020). Using mullite particles in varying weight ratios of 0, 20, 40, and 60%, a composite material comprising unsaturated polyester resin was created for this study. The samples were examined to determine how the addition of mullite affected the composite's mechanical characteristics. Following reinforcement, the hardness and tensile strength increased as the mullite content rose [24].

A. H. Majeed and S. Q. Ibrahim, (2017). In this work, polymer matrix composites were created by mixing unsaturated polyester resin with carbon black (CB), silica fume (SF), and glass powder (GP). Fillers were added one at a time in various ratios: 0%, 0.5%, 1%, 1.5%, 2%, 2.5%, and 3%. The findings indicate that adding GP, SF, and CB to the polymer matrix increases its hardness. When silica fume is added to the polymer matrix, compressive strength increases, whereas GP and CB cause a decrease in compressive strength [25].

II. EXPERIMENTAL WORK

A. Matrix Material

Egyptian Unsaturated Polyester Resin (USP-EAGLE (GP180-65) was used as a base material in the preparation of the polymeric composite material which manufactured by EAGLE chemicals company. It is in the form of a transparent pink liquid at room temperature. It is a type of thermosetting polymer, this resin turns from liquid state to solid state by the addition hardener (catalyst) (Methyl Ethyl Ketone Peroxide) which manufactured by the same company EAGLE, which is in the form of a transparent liquid added to the unsaturated polystyrene resin at (20 mL) per (1000 mL) of resin at room temperature [26]. (Figure 1) shows the type of unsaturated polyester used in the present research. (Figure 2) shows the structure of unsaturated polyester resin.

B. Reinforcement Material

The chemical composition of loofah primarily comprises lignin and hemicellulose/cellulose, along with various inorganic elements such as glycosides, polypeptides, amino acids, proteins, and more [27–29]. The hemicellulose content varies from 8% to 22%, while the lignin content ranges from 10% to 23%. On the other hand, the cellulose content falls between 55% and 90%. The physical and chemical properties of loofah are presented in (TABLE I) During the initial phase of luffa growth, its cellular structure consists of multiple individual fibers, which eventually transform into a fibrous mat by the end of the process [29]. Six samples of (NWSL) were prepared with different volumes (5, 10.20, 30, 40 and 50% vol.) of the hardened polyester sample. The fiber and the different volumes of (NESL) are shown in (Figures 3a and 3b) respectively. The loofah sponge used in the experiments of this research was attained from (Al- Saida Easha) Friday Local Market in Cairo- Egypt which was vended as a bath sponger.

In the present investigation, the hardness and compressive strength fabrication following the guidelines of, ASTM D2240, [30] and ASTM D695-10, [31] respectively. The dimensions of the mould samples are as depicted in (Figure 4a).

Fig. 1. Egyptian (EAGLE) Unsaturated Polyester.

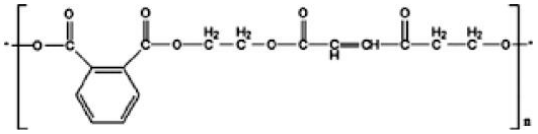

Fig. 2. Structure of Unsaturated Polyester.

Three samples were created for each volume of (NESL) fiber that was going to be added to the saturated polyester in order to compute the average of the three samples. There were twenty-one samples mounted in all. The hand layup technique was utilized during casting, followed by conducting hardness and compressive strength tests to assess the final models. To initiate the preparation of the unsaturated polyester material, the resin, with a volume of 1000 mL, was blended with the hardener, Methyl Ethyl Ketone Peroxide, in the prescribed amount of 20 mL. (TABLE II) lists the properties of the polyester resin [32]. The combination of resin and hardener was manually mixed for around two minutes, after which it underwent degassing in a vacuum oven at 80 °C to eradicate any air bubbles [33]. The (NELS) fiber samples of varying volumes were prepared (5, 10, 20, 30, 40 and 50% volume of mould and subsequently dried in an oven at 60º C for a period of 24 hours in order to remove any excess moisture content [33]. The desiccated (NELS) fiber is then delicately inserted into the plastic mold, ensuring that it is evenly distributed throughout the entire volume of the mold. The casted samples were allowed to harden in the mold for a period of 48 hours at room temperature until they were fully solidified. Subsequently, the specimens were taken out of the mold and polished with an abrasive to ensure a flat and smooth surface, preparing them for compression testing. Figure (4b) displays the plastic molds utilized in the production of the cured polyester. (Figure 5) shows the hardened polyester samples with and without (NESL) fiber for compressive strength.

TABLE I: Loofah Fibers Physical Properties and Chemical Composition [29].

Physical Properties				Chemical Properties			
Density (g/cm³)	Diameter (cm)	Aspect Ratio	Micro Fibrillar Angle (°)	Cellulose (%)	Lignin (%)	Hemi Cellulose (%)	Ash (%)
0.56-0.92	0.027	340± 5.0	12.00± 2.0	63.00± 2.5	11.69± 1.2	20.88± 1.4	0.40± 0.10

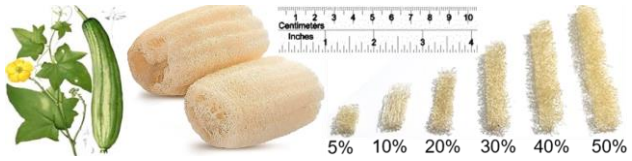

Fig. 3a. (NESL) Fiber Sample. Fig. 3b. The Six Volumes of (NESL).

TABLE II: Properties of the Polyester Resin [32].

Property	Unsaturated Polyester
Density (g/cm³)	1.2 to 1.5
Young's modulus (MPa)	2000 to 4500
Tensile Strength (MPa)	40 to 90
Compressive Strength (MPa)	90 to 250
Tensile Elongation at Break (%)	2
Cure Shrinkage (%)	4 to 8
Water Absorption 24 h at 20 °C	0.1 to 0.3

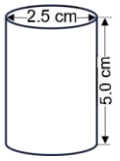

Fig. 4a. Mould Dimensions.

Fig. 4b. Plastic Molds.

Fig. 5. The Hardened Polyester Samples with and without (NESL) Fiber for Compressive Strength.

III. Results and Discussion

A. Calculated Density

In order to calculate the density of cured polyester samples with and without the filled with different volumes of (NESL) fiber, the (Equation 1) was used [34]:

$$D = Ws/V \quad (1)$$

Where, Where, D is the density of the sample in (g/cm³), Ws is the weight of the sample in gram (g) and V is the volume of the sample in (m³). The (TABLE III) listed the data of hardened (NESL) fiber samples including; the sample, weight, volume, density, average of density and percentage drop of density with increasing the volume of (NELS) fiber composite.

Unsaturated polyester is a type of resin that hardens when exposed to heat. Therefore, in theory, the size of the sample should decrease after the curing process [35]. This was validated by the average density values of unsaturated polyester found in this study. When unsaturated polyester is in its liquid state, its density ranges from (1.2 to 1.5 g/cm³), as shown in (Table II). Once it solidifies, the density of unsaturated polyester decreases to approximately (1.12 g/cm³), as indicated in (TABLE III).

Both the liquid and solid phases produced the same mass of unsaturated polyester, but the solid stage's volume was reduced due to a difference in density. It's interesting to note that the density of unsaturated polyester remained nearly constant for all initial curing temperatures; the largest density reduction was only 0.42% when 50% (NESL) of the mould volume was added to the unsaturated polyester. As a result, when the volume of the fiber increases, the density of the cured sample combined with (NESL) fiber decreases, and the volume shrinkage of unmatured polyester is independent of the initial curing temperature [36]. The relationship between the average density of the cured samples and the volume of (NESL) fiber included in the cured unsaturated polyester samples is depicted in (Figure 6).

TABLE III: The Data of Hardened (NESL) Fiber Samples.

Sample Code	NESL Fiber (%)	Sample Weight (g)	Sample Volume (cm³)	Sample Density (g/cm³)	Density Average (g/cm³)	Density Drop (%)
L1A	00	25.12	22.32	1.1256	1.1259	0.00
L1B	00	25.12	22.32	1.1256		
L1C	00	25.14	22.32	1.1265		
L2A	05	25.12	22.32	1.1256	1.1250	0.08
L2B	05	25.11	22.32	1.1251		
L2C	05	25.09	22.32	1.1242		
L3A	10	25.09	22.32	1.1242	1.1244	0.13
L3B	10	25.10	22.32	1.1247		
L3C	10	25.09	22.32	1.1242		
L4A	20	25.08	22.32	1.1238	1.1238	0.19
L4B	20	25.07	22.32	1.1233		
L4C	20	25.09	22.32	1.1242		
L5A	30	25.07	22.32	1.1233	1.1236	0.20
L5B	30	25.09	22.32	1.1242		
L5C	30	25.07	22.32	1.1233		
L6A	40	25.03	22.32	1.1215	1.1227	0.28
L6B	40	25.06	22.32	1.1229		
L6C	40	25.08	22.32	1.1238		
L7A	50	25.04	22.32	1.1220	1.1212	0.42
L7B	50	25.05	22.32	1.1224		
L7C	50	24.98	22.32	1.1193		

B. Hardness Test

As a function of the stress necessary to cause a certain type of surface deformation, hardness is a measure of the resistance to penetrating the surface [37].

A Micro Vicky VH1010 Digital Micro Hardness Tester as shown in (Figure 7a) was used to measure the microhardness of cured samples. The usual range of loads is 10gm to 1kgf, however "Macro" Vickers loads can go up to 50 kg or higher [38]. As per ASTM D2240 [30], sample dimension was chosen as a diameter of 4 cm and a thickness of 1 cm. The test's casting plastic moulds and their dimensions are displayed in (Figures 7b and 7c) respectively. Cured samples are shown in (Figure 7d). Six of the seven samples had varying amounts of (NESL) fiber added to them, making up (5, 10, 20, 30, 40, and 50% of the mould volume). The seventh sample had no (NESL) fiber at all. The cured samples have to be thick enough and have a smooth surface. Each sample's surface received three evenly spaced indentations separated by at least 0.5 mm and the average of these readings was determined to obtain the hardness value. Microhardness obtained using the (Equation 2), [39]:

$$Hv = 1.854\ P / d^2 \quad (2)$$

Where, Hv is the Vickers hardness in (Kgf/mm²), P is the load in (Kgf) and d is the length of the diagonals in (mm). (TABLE IV) lists the parameters related to hardness test, including; the load and the Vickers hardness. As can be shown in (Figure 8), the hardness of unsaturated polyester is influenced by the (NESL) fiber volume percentage (%). It is observed that when the volume percentage of (NESL) fiber increased in the unsaturated polyester composite material grows, so does

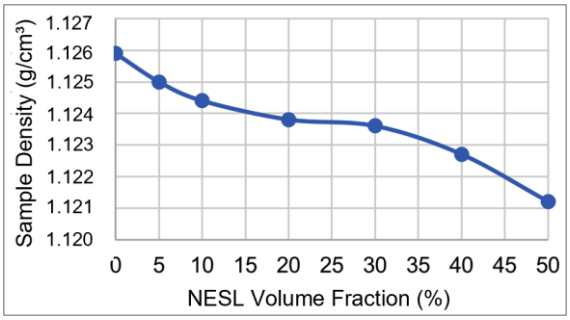

Fig. 6. The Density of Unsaturated Polyester Composites with Various (%) Additions of (NESL) Fiber.

the samples' hardness values; in other words, the presence of (NESL) fiber increases the material's resistance to plastic deformation.

C. Compressive Strength Test

The value of uniaxial compressive stress attained when a material fails totally is its compressive strength. Using (Equation 3), [42] one may compute the compressive strength:

$$\sigma = F/A \quad (3)$$

Where, F is the failure load in Newton (N) and A is the cross-sectional surface are of the cured sample in (m²), the cross-sectional area of the cured sample was calculated using the (Equation 4), [42]:

$$A = \pi r^2 \quad (4)$$

The computed area (A) of the fixed sample dimensions was found to be (4.909×10^{-4} m²), where r is the sample's radius in meters (m).

The distribution of the load on the (NESL) fibers decreases the rate at which the surface of the composite material is penetrated and increases the values of its hardness; this outcome is consistent with [40, 41]. As a result, the material stiffens and becomes more resistant to scratches.

A Krystal Tester as shown in (Figure 9) was used to measure the compressive strength of cured samples. It is intended specifically for small components up to 10 kN in low load capacity and beneficial for determining the compressive strength of rubber, plastic, thermoform, springs, and numerous other non-metallic materials that are comparable [43].

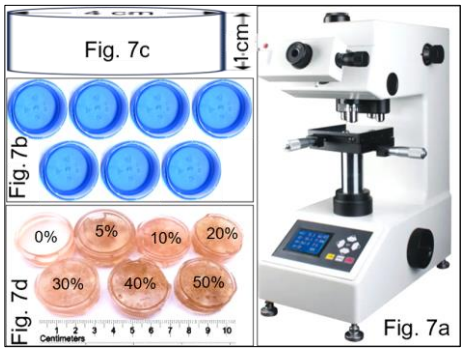

Fig. 7a. VH1010 Digital Micro Hardness Tester, Fig. 7b Plastic Mould Samples, Fig. 7c Mould Sample Dimensions, Fig. 7d Cured Samples.

TABLE IV: The Parameters of Hardness Test.

Sample Code	NESL (% vol.)	Test Location	Vickers Hardness (Hv)	Vickers Hardness Average (Hv)
LI	00	A	36.13	40.21
		B	40.85	
		C	43.64	
LII	05	A	37.39	38.90
		B	38.07	
		C	33.25	
LIII	10	A	39.44	42.42
		B	42.59	
		C	45.23	
LIV	20	A	46.86	51.00
		B	55.03	
		C	51.11	
LV	30	A	59.43	62.17
		B	61.99	
		C	65.10	
LVI	40	A	71.52	70.87
		B	72.14	
		C	68.95	
LVII	50	A	69.02	71.84
		B	75.96	
		C	70.55	

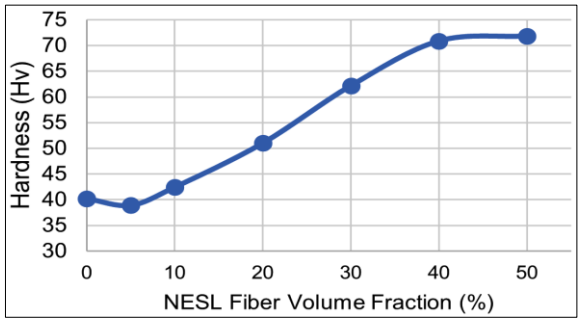

Fig. 8. Hardness Vs. NESL Fiber Volume Fraction.

The sample dimensions of 2.5 cm in diameter and 5 cm in height were selected in accordance with ASTM D695-10, [31] (Figure 4a). Different amounts of (NESL) fiber were added to 18 cured samples, which accounted for 5, 10, 20, 30, 40, and 50% of the plastic mould capacity. Three additional cured samples exhibited zero (NESL) fiber; it was paraffin wax applied on the inside to stop it from sticking [44]. The applied load and compressive strength values are listed in (TABLE V).

The device's diagram was used to directly determine the compressive strength values. The relationship between the prepared samples' compressive strength and the volume fraction of (NESL) fiber is depicted in (Figure 9). The unsaturated polyester composite material's compressive strength can be enhanced by increasing the volume fracture of (NESL) fibers, as this figure shows. This is because these (NESL) fibers play a significant role in the unsaturated polyester composite materials' ability to transfer stress. These (NESL) fibers will strengthen the composite by preventing the unsaturated polyester chains from moving about inside it. This result is consistent with the idea that resin penetration in

TABLE V: The Parameters of Compressive Strength Test.

Sample Code	NESL Fiber (%)	Failure Load (F) (N) x10^3	Compressive Strength (σ) (MPa)	(σ) Average (MPa)	(σ) Increase (%)
L1A	00	172.21	35.08	35.91	0.00
L1B	00	183.69	37.42		
L1C	00	172.99	35.24		
L2A	05	219.19	44.65	42.42	28.36
L2B	05	196.56	40.04		
L2C	05	208.93	42.56		
L3A	10	224.34	45.70	46.21	38.16
L3B	10	237.35	48.35		
L3C	10	218.84	44.58		
L4A	20	271.66	55.34	53.33	45.26
L4B	20	255.91	52.13		
L4C	20	257.82	52.52		
L5A	30	272.45	55.50	57.96	57.29
L5B	30	278,73	56.78		
L5C	30	272.89	55.59		
L6A	40	305.54	62.24	62.60	61.88
L6B	40	309.56	63.06		
L6C	40	306.91	62.52		
L7A	50	303.77	61.88	61.57	60.95
L7B	50	301,76	61.47		
L7C	50	301,21	61.36		

(NESL) fiber will lessen the likelihood of (NESL) fiber withdrawing or separating from the base material [45].

As depicted in (Figure 9), the unsaturated polyester composite including (NESL) fiber exhibited the highest increase in compressive strength, reaching 62.60 MPa at a 40% (NESL) fiber volume fraction. This improvement in compressive strength was almost 60% greater than that of the samples lacking (NESL) fiber.

Fig. 8 Krystal Compressive Strength Tester.

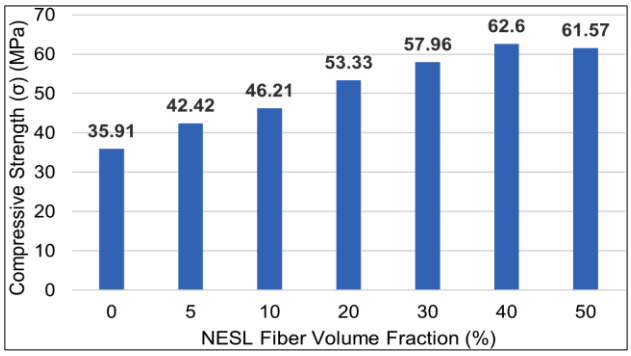

Fig. 9. Compressive Vs. NESL Fiber Volume Fraction.

IV. CONCLUSIONS

This study examined the density, hardness, and compressive strength of polyester resin composites reinforced with Egyptian sponge (EAGLE) unsaturated with varying natural Egyptian sponge loofah (NESL) fiber. For fabrication, varying amounts of (NESL) Fiber in relation to the volume of cured samples have been taken (5, 10, 20, 30, 40, and 50% vol.). The findings of the density calculation show that when the amount of (NESL) fiber increases from 5 to 50% vol., the density of the cured samples that were combined with the composite had a very slight decrease, going from 1.1259 g/cm³ to 1.1212 gm/cm³. The interface adhesion properties of the matrix and (NESL) fiber are to blame for this.

Hardness and compressive strength, two mechanical attributes, have improved. When the amount of (NESL) fiber grows from 5 to 50% vol., the average hardness increases from 38.90 HV to 71.84 HV as the volume fraction of additional (NESL) fibers increases. In the meantime, when the proportion of (NESL) fiber increases from 5 to 40% vol., the average compressive strength rises from 42.42 MPa to 62.60 MPa. For (NESL) fibre composites, the ideal filler content percentages were 50% vol. and 40% vol., which resulted in notable increases in compressive strength and hardness. Generally, results indicated better hardness and compressive strength for cured Egyptian (EAGLE) unsaturated polyester when 40% vol. of (NESL) fibers were applied as a composite material.

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